

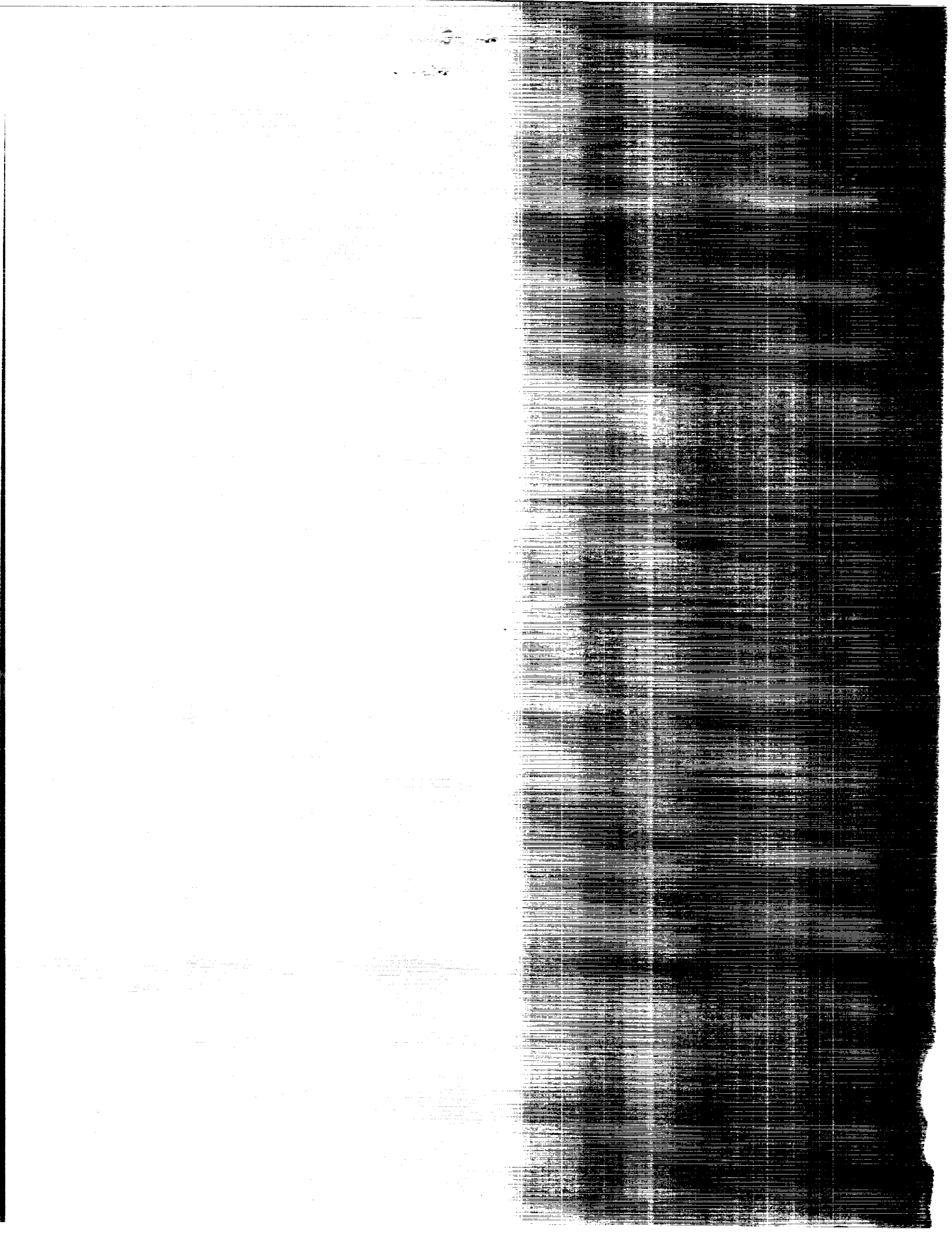
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EFFECTS ON STING-BALANCE DEFLECTIONS IN THE  
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# Cryogenic Temperature Effects on Sting-Balance Deflections in the National Transonic Facility

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## Abstract

An investigation was conducted in the National Transonic Facility (NTF) at Langley Research Center to document the change in sting-balance deflections from ambient to cryogenic temperatures. Space limitations in some NTF models do not allow the use of onboard angle-of-attack instrumentation. To obtain angle-of-attack data, predetermined sting-balance bending data must be combined with arc-sector angle measurements. Presently, obtaining pretest sting-balance data requires several cryogenic cycles and cold loadings over a period of several days. A method of reducing the required calibration time is to obtain only ambient-temperature sting-balance bending data and to correct for changes in material properties at cryogenic temperatures. To validate this method, two typical NTF sting-balance combinations were tested. The test results show excellent agreement with the predicted values, and the repeatability of the data was  $0.01^\circ$ .

## Introduction

Large changes in temperature alter the material properties of wind-tunnel sting-balance support systems and affect the amount of angular deflection during testing. The National Transonic Facility (NTF) at Langley Research Center is a transonic wind tunnel that uses cryogenic nitrogen gas to achieve high Reynolds numbers for aerodynamic testing. The operating-temperature range for the tunnel is from  $140^\circ\text{F}$  to  $-300^\circ\text{F}$  and the stagnation-pressure range is from 14.7 to 130 psia. The Mach number range of the NTF is from 0.2 to 1.2.

The preferred method of measuring angles of attack and sideslip for wind-tunnel models is to have an onboard measuring system; however, because of space limitations in some NTF models, this method is not always feasible. Hence, data from the arc-sector (model support strut) pitch angle, the roll output angle, and the predetermined sting-balance bending characteristics must be combined to compute the model attitude. In models with an onboard angle-measuring system, the arc-sector pitch angle, roll output angle, and the sting-balance bending data serve as a backup method for measuring angles. A typical set of sting-balance deflection measurements includes the contributions due to the following model loadings: normal force, pitching moment, side force, and yawing moment. Because of changes in material properties over the tunnel operating-temperature range, the sting and balance stiffness varies and the deflection angle changes. Currently, in order to measure this sting-balance deflection change prior to tunnel testing, static weight loadings at several cryogenic

temperatures are necessary. One of the NTF model assembly bays has a cryogenic chamber designed for performing these weight loadings. This measurement process requires several time-consuming cryogenic cycles and weight loadings.

The purpose of this investigation is to assess mathematical predictions of deflection changes with temperature. If deflection changes can be predicted accurately, cryogenic loadings can be eliminated. Eliminating these cryogenic loadings will result in significantly reduced model preparation time. The predicted cryogenic deflections are determined by correcting ambient-temperature deflections for temperature effects on material properties. To investigate the accuracy of the predicted values, two sting-balance combinations were cooled to cryogenic temperatures, were loaded, and the deflections were measured. The results of these loadings were then compared with the predicted sting-balance bending values.

## Symbols

$E$	Young's modulus of elasticity, lb/in <sup>2</sup>
$I$	area moment of inertia, in <sup>4</sup>
$K_m$	pitching-moment bending coefficient, deg/in-lb
$K_N$	normal-force bending coefficient, deg/lb
$L$	sting length, in.
$M$	pitching moment, in-lb
$N$	normal force, lb
NTF	National Transonic Facility
$T$	temperature, $^\circ\text{F}$
$\theta$	sting-balance deflection angle, deg
$\theta_m$	sting-balance deflection angle due to pitching moment, deg
$\theta_N$	sting-balance deflection angle due to normal force, deg

## Apparatus

All sting-balance deflection loadings were performed in the NTF cryogenic chamber located in a model-assembly bay. This chamber (fig. 1) is capable of cryogenic cycling a test model and sting for instrumentation checkout. The cryogenic chamber has a sting-backstop system that allows pitch, roll, and

height adjustments. The cryogenic chamber uses a liquid nitrogen injection system to achieve test temperatures down to  $-300^{\circ}\text{F}$ . For sting-deflection loadings, slots in the floor of the cryogenic chamber permit access to a weight basket below (ref. 1).

Figure 2 shows sketches of the NTF balances, model stings, and stub stings tested. Sting-balance combination 1 consists of the NTF-104 balance, the X-29 model sting, and NTF stub sting 2. Sting-balance combination 2 has the NTF-113 balance, NTF model sting 1, and NTF stub sting 2. The NTF balance material is 18 Ni 200 grade maraging steel (VascoMax 200<sup>1</sup>). Surrounding the balance is an 18 Ni 200 grade maraging steel calibration block, which provides a loading surface for the weight-loading rig (fig. 3). The weight-loading rig has a double knife-edge loading attachment that rests in a calibration-block groove. The calibration block connects to the balance by a front-end-attachment cylindrical fit and a dowel pin, which transfer all loads to the balance gages. The weight-loading rig also contains a frame, a shackle, and a connecting rod. The total weight of the loading-rig assembly is approximately 200 lb.

The two model stings are made from 18 Ni 200 grade maraging steel. Dimensions for the two sting-balance combinations are shown in figure 4. The balance connects with a taper joint and key to the model sting. Two Armco Nitronic 60 10-32 set screws secure this joint. The stub sting material is ASTM A638 grade 660 steel. The model sting connects to the stub sting by a taper joint secured with four Nitronic 60 3/8-24 bolts and a key. At the backstop joint, the threaded stub sting secures to the backstop with a Nitronic 60 13-2 nut.

Sting-balance deflection angles were defined as the difference between the angles of two cryogenic inertial-accelerometer packages. The front accelerometer was mounted on the balance calibration block. The rear accelerometer was attached to a leveling plate mounted on the stub sting. The distance between these two accelerometers was 110 in. The accuracy of these accelerometers was  $0.01^{\circ}$ . For monitoring temperature gradients, a network of copper-constantan thermocouples were mounted inside and outside the model sting and the stub sting.

## Determination of Deflection Angles

The applied loads simulated the aerodynamic model loads that would be transmitted to a sting-balance system during tunnel operations. The no-load configuration included the loading rig assembly hanging from the leveled calibration block. The

range of sting bending test temperatures was from  $75^{\circ}\text{F}$  to  $-225^{\circ}\text{F}$ ; data taken at  $75^{\circ}\text{F}$  increments. The loadings began when the balance and model sting reached the steady-state test temperature. After the addition of each weight to the loading rig, the calibration block was returned to a level position, so that the applied forces were perpendicular to the balance centerline. The level position was obtained by using an electrolytic bubble that was located within the accelerometer package. The sting-balance deflection for each load was defined as the change in the angle between the calibration block and the stub sting from the no-load value.

A cantilever beam with an end load and an applied bending moment can represent a sting-balance system. Equation (1) gives the angular deflection due to a normal-force end load as follows:

$$\theta_N = (NL^2)/(2EI) \quad (1)$$

Equation (2) shows the angular deflection of a cantilever beam that results from a pitching moment at the free end (ref. 2) as follows:

$$\theta_m = (ML)/(EI) \quad (2)$$

By applying the method of superposition, these two equations can be combined to calculate the total sting-balance deflection angle as follows:

$$\theta = \theta_N + \theta_m \quad (3)$$

The superposition of these two loadings simulates a model with normal-force and pitching-moment loadings. The terms in the deflection equations that are subject to thermal change are the sting length, area moment of inertia, and Young's modulus of elasticity. For this test, the pure normal-force loadings were accomplished by hanging the weights over the moment center of the balance. Pure pitching-moment loading could not be performed. Therefore, combined pitching-moment and normal-force loadings were performed by hanging the weights 2 in. forward and aft of the balance moment center. To determine values for side-force and yawing-moment loadings in the NTF cryogenic chamber, the sting and balance must be rotated  $90^{\circ}$ . Only normal-force and pitching-moment loadings were performed for this test.

For sting-balance combination 1, the deflection data formed a system of linear equations. At each test temperature, the deflection data fit the following equation:

$$K_N N + K_m M = \theta \quad (4)$$

<sup>1</sup> Trademark of Teledyne Vasco.

In equation (4),  $K_N$  is the normal-force bending coefficient, and  $K_m$  is the pitching-moment bending coefficient. A simultaneous equation solver that used a first-order, least-squares fit determined the values for  $K_N$  and  $K_m$ . Although solving for the unknowns required only two distinct loadings, the equation solver processed the entire data set and, therefore, increased the confidence in calculating values for  $K_N$  and  $K_m$ . For sting-balance combination 2, there were only normal-force loadings. The deflection data fit the following equation:

$$K_N N = \theta \quad (5)$$

A first-order, least-squares fit of the data determined the value of  $K_N$  at each temperature. The criterion for a successful curve fit was a difference of less than  $0.01^\circ$  between the test data and the corresponding least-squares-fit values.

## Results and Discussion

Figure 5 shows the deflection results of the ambient and cryogenic loadings for sting-balance combination 1. The deflection data vary linearly with normal-force and pitching-moment loadings. Loading and unloading data were taken at each weight increment. The data show good repeatability between the weight loading and unloading data points. The linearity indicates elastic bending, and the good repeatability indicates properly fitting sting and balance joints.

In the cantilever-beam deflection equations, the two material properties that affect deflection are the coefficient of thermal expansion (by way of length and area moment of inertia) and Young's modulus of elasticity. For 18 Ni grade 200 maraging steel, the average coefficient of thermal expansion over this temperature range is  $4.2 \times 10^{-6}$  in/in- $^\circ\text{F}$  (ref. 3). Calculations show a decrease of 0.1 percent in sting length and 0.5 percent in the area moment of inertia for a temperature change from  $75^\circ\text{F}$  to  $-225^\circ\text{F}$ . Also, for this test-temperature range, the material has a linear increase in Young's modulus of elasticity of 4.2 percent (ref. 4). From these calculations, a 3.7 percent decrease in sting-balance bending coefficients should occur over this temperature range. With the ambient-temperature bending coefficients as a starting point, normal-force and pitching-moment bending coefficients were calculated for the test-temperature range. Figure 6 shows the variation in the normal-force bending coefficients for sting-balance combinations 1 and 2 over the test-temperature range. Sting-balance combination 1 has a 3.3-percent decrease from  $75^\circ\text{F}$  to  $-225^\circ\text{F}$ . For sting-balance combination 2, the decrease in  $K_N$  is

3.9 percent over the same temperature range. Figure 7 shows a 4.7-percent decrease in the pitching-moment bending coefficient over the test-temperature range for sting-balance combination 1. Pitching-moment data were taken only for sting-balance combination 1. There was a difference in deflection angle of less than  $0.01^\circ$  between the test data and the corresponding least-squares-fit values. These results show that the change in sting-balance deflection over the NTF operating-temperature range can be predicted with sufficient accuracy.

Maintaining small sting temperature gradients during testing was essential for a successful test. The rear of the stub sting, exposed to ambient temperature, has a relatively large thermal mass, which restricts complete cool-down. However, only a  $15^\circ\text{F}$  gradient existed between the balance and rear of the model sting. This small gradient assured that the material properties were essentially the same in the region where most of the bending occurred. Thermocouples located in the balance and model-sting joint and in the model-sting and stub-sting joints showed a maximum gradient of  $10^\circ\text{F}$  at the coldest temperature. These small gradients were not significant to the sting-balance deflection results.

The method of predicting sting-balance deflections from changes in the metallurgical characteristics with temperature can be readily incorporated into NTF operations. Ambient loadings are essential for calculating sting-balance deflections. The loadings assure that the sting joints are secure and provide values for the ambient reference bending coefficients ( $K_N$  and  $K_m$ ). The results of this test show that the bending coefficients vary linearly as a function of sting temperature. During NTF operations, the sting temperature is essentially the stream stagnation temperature. Thus, either the sting temperature or the tunnel stagnation temperature may be used in calculating the bending coefficients. The NTF force-and-moment balance resolves the aerodynamic loads into individual components. To calculate the angular deflection due to sting-balance bending, each resultant force and moment is then multiplied by the proper deflection coefficient. These deflections, along with the arc-sector pitch angle and roll output angle, make possible the calculation of model orientation (i.e., angles of attack and sideslip).

During NTF wind-tunnel testing, there is some movement between the stub sting and the arc-sector pitch-angle measuring device. Including this small amount of movement with the results from this investigation establishes the accuracy of the sting-balance deflection angles to  $0.05^\circ$ . The accuracy was determined by comparing test data having an onboard

angle-of-attack accelerometer with angles calculated from sting-balance deflections.

Using the predicted cryogenic sting-balance deflection method will save model preparation time. Presently, several cryogenic loadings of the sting-balance system are required to determine bending coefficients. A typical set of cryogenic sting-balance deflection measurements includes loadings for normal force, pitching moment, side force, and yawing moment. A set of these deflections involves separate cryogenic cycles; each cycle takes 1 day to complete. The new method requires only ambient-temperature loadings and each loading takes approximately 1 hr; the new method results in significant time savings.

## Concluding Remarks

A more efficient method of determining National Transonic Facility (NTF) sting-balance deflections can replace the present time-consuming method. The current method requires cooling the sting and balance to cryogenic temperatures for a series of weight loadings and typically takes several days to complete. The new method requires loadings only at ambient temperature. From these loadings, the changes in deflection due to changes in the coefficient of thermal expansion and Young's modulus of elasticity with temperature are calculated. The time necessary for the new method is several hours.

In tests conducted to show the accuracy of the new method, two sting-balance combinations were cooled to cryogenic temperatures and deflection loadings were performed. These deflections were then

compared with results predicted by the new method. Over the temperature range of 75°F to -225°F, the new method predicted a decrease of 3.7 percent for both the normal-force and pitching-moment deflection coefficients. In two experimental tests performed to determine the normal-force deflection coefficient, decreases of 3.3 percent and 3.9 percent occurred. The one experimental pitching-moment test had a 4.7-percent decrease in pitching-moment deflection coefficient over the same temperature range. In the cryogenic chamber, the repeatability of the deflection data was 0.01°. For wind-tunnel testing, the accuracy of the model attitude measurements using the new method of calculating sting-balance deflections was 0.05°.

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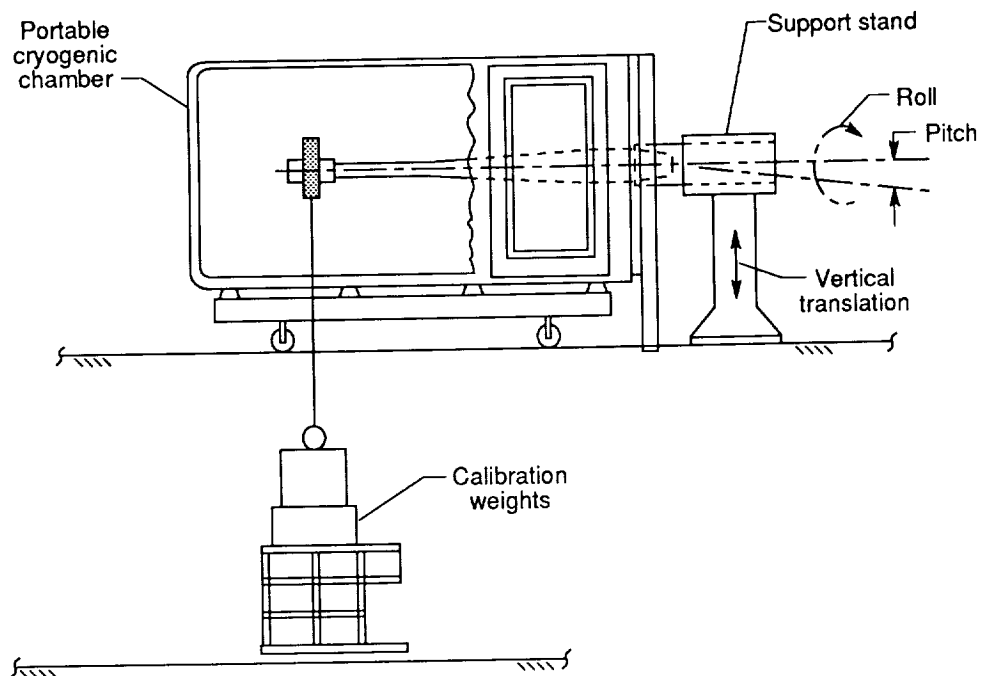


Figure 1. NTF cryogenic chamber.

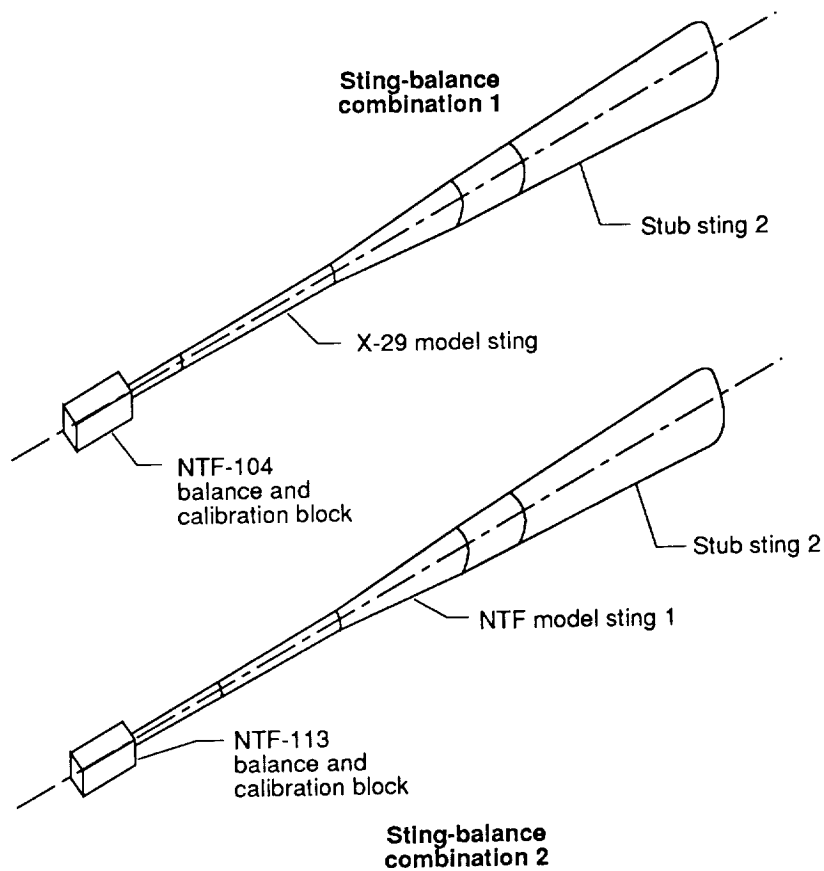


Figure 2. Sting-balance combinations.

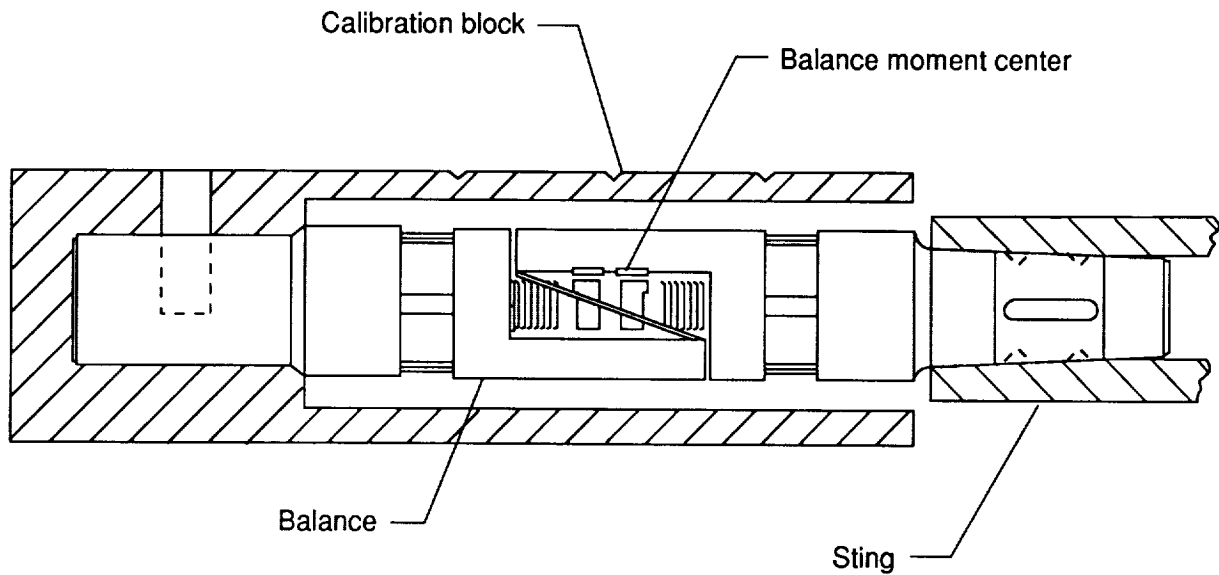
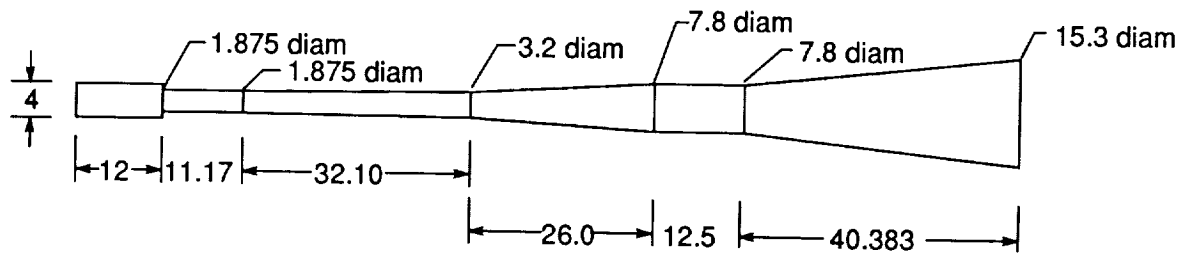


Figure 3. NTF calibration block and balance.

#### Sting-balance combination 1



#### Sting-balance combination 2

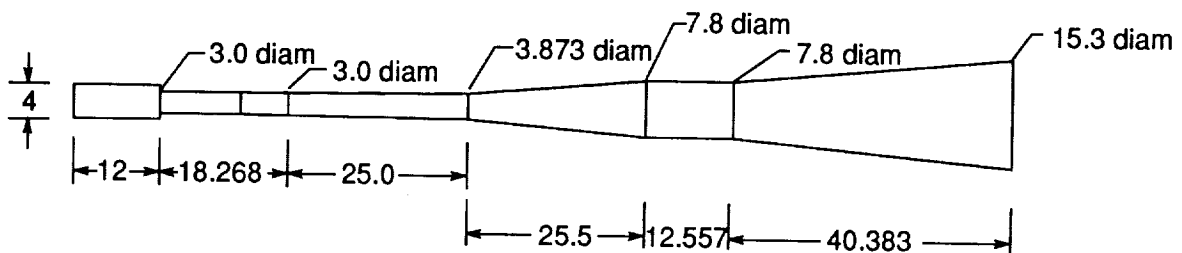


Figure 4. Sting-balance combination dimensions. All dimensions are in inches.

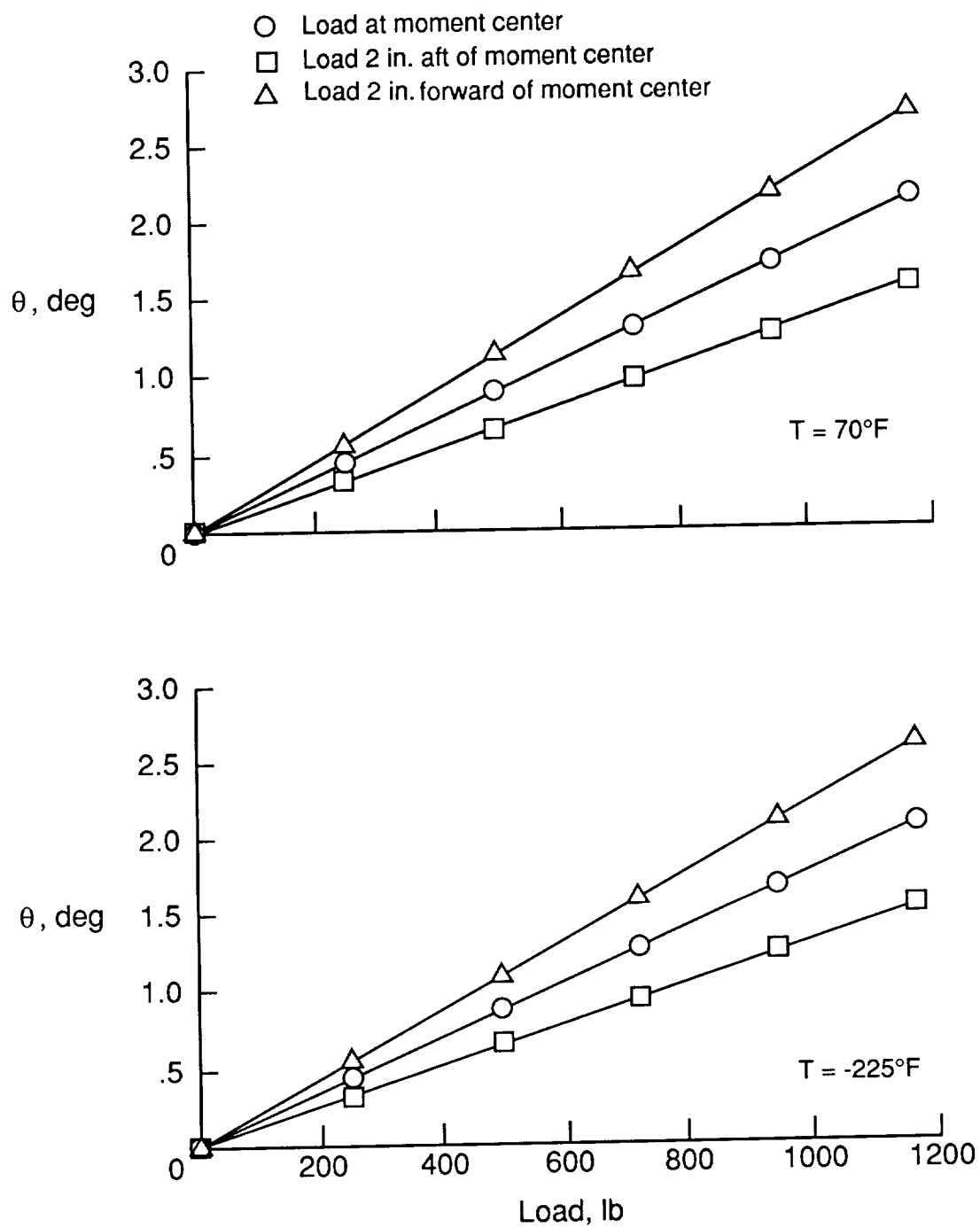


Figure 5. Deflections for sting-balance combination 1.

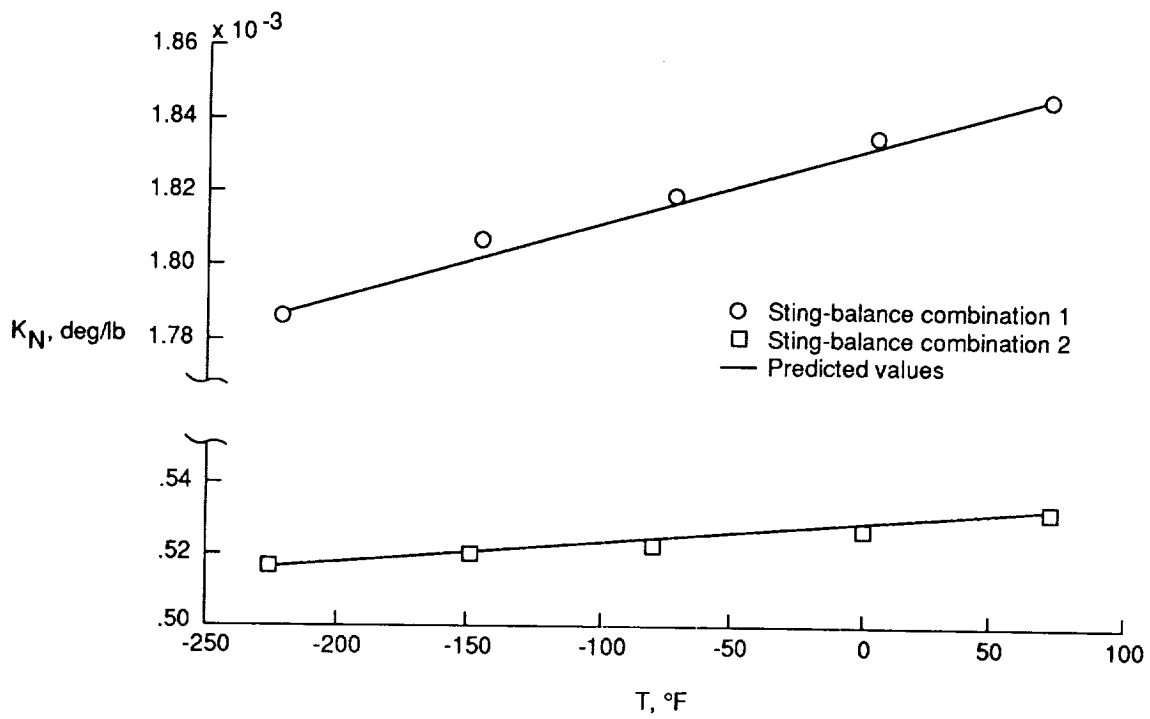


Figure 6. Normal-force bending coefficients.

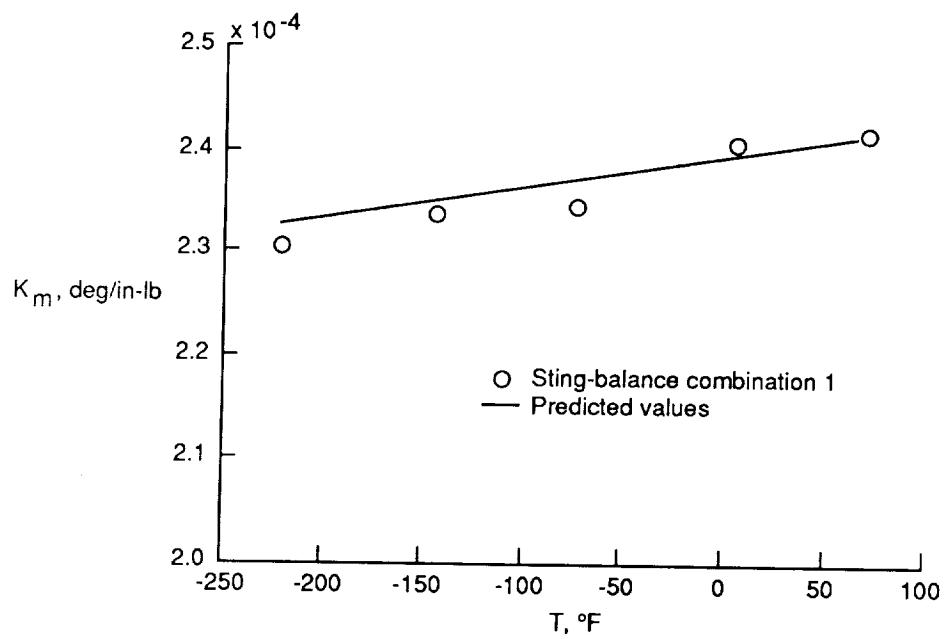


Figure 7. Pitching-moment bending coefficients.



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